Mechanical Properties of Shot-Peened Silicon as Measured by Nanoindentation

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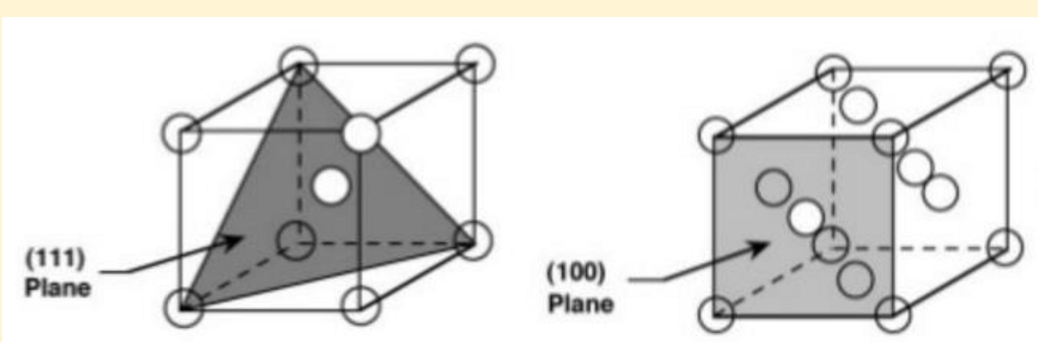
Introduction

- Silicon (Si) is a semiconductor essential to the electronics industry.
- Si is a also a brittle material, and tedious care is required to manufacture small components out of it.
- Si also has different properties depending on the level of dopant. A common type of dopant is n-type, which uses Phosphorus.
- Shot Peening has been proven to induce beneficial stress fields into materials in order to improve strength and reduce fracture toughness.
- Nanoindentation is a reliable non-destructive means of testing mechanical properties of materials by indenting the material on the order of 10^{-9} meters.



Single Crystal Si forms a cubic matrix which has multiple slip planes. Two such planes are shown above.

Objectives

Nanoindentation will be used to compare the effects of dopant and orientation in Si. It will also be used to determine if bombardment with glass shot induces beneficial defects in Si that increase ductility or decrease brittle fracture.

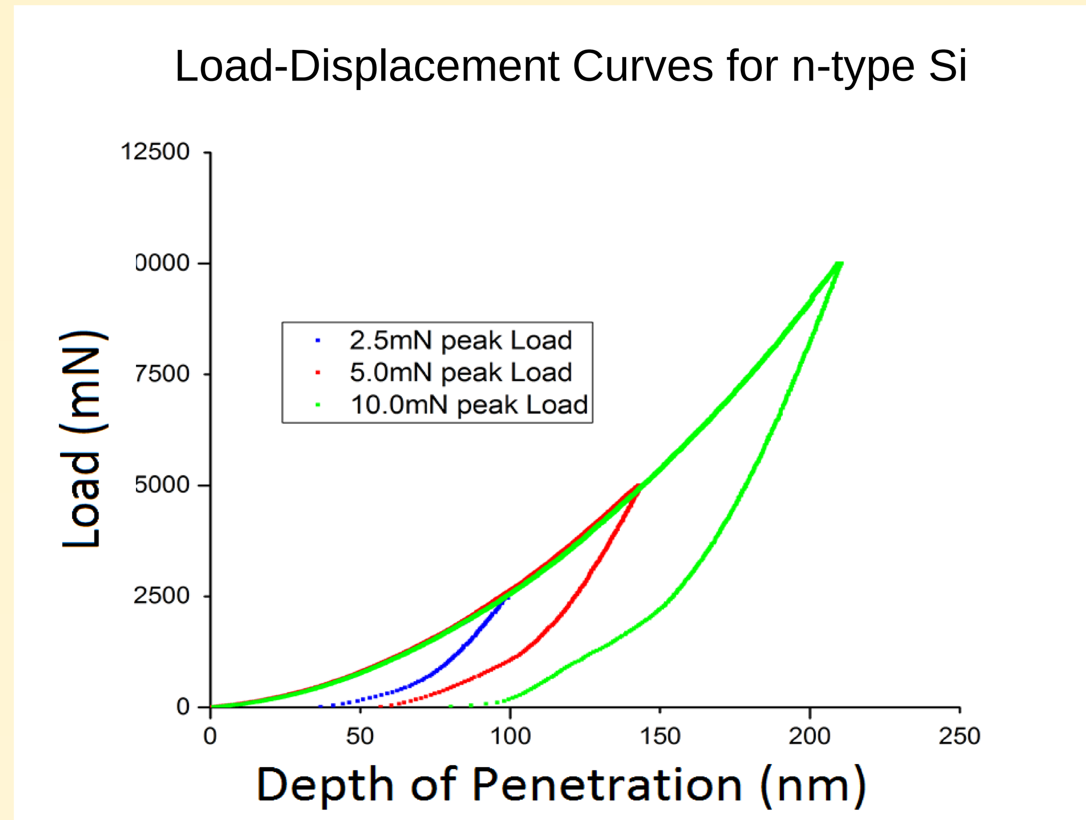
Methods

- A Hysitron TI-900Triboindenter® was used with a Berkovitch (3 sided pyramidal) indenter.
- N-type <111>, n-type <100>, intrinsic <111>, and intrinsic <100> Si wafers were compared in an initial study on the effect of dopant and orientation of hardness and modulus.
- A N <111> wafer was shot peened with a Zero Blast 'n Peen (® Chemco Industries) at room temperature. Indentation was then done at varying distances from a crater to identify any presence of beneficial compressive stress fields.

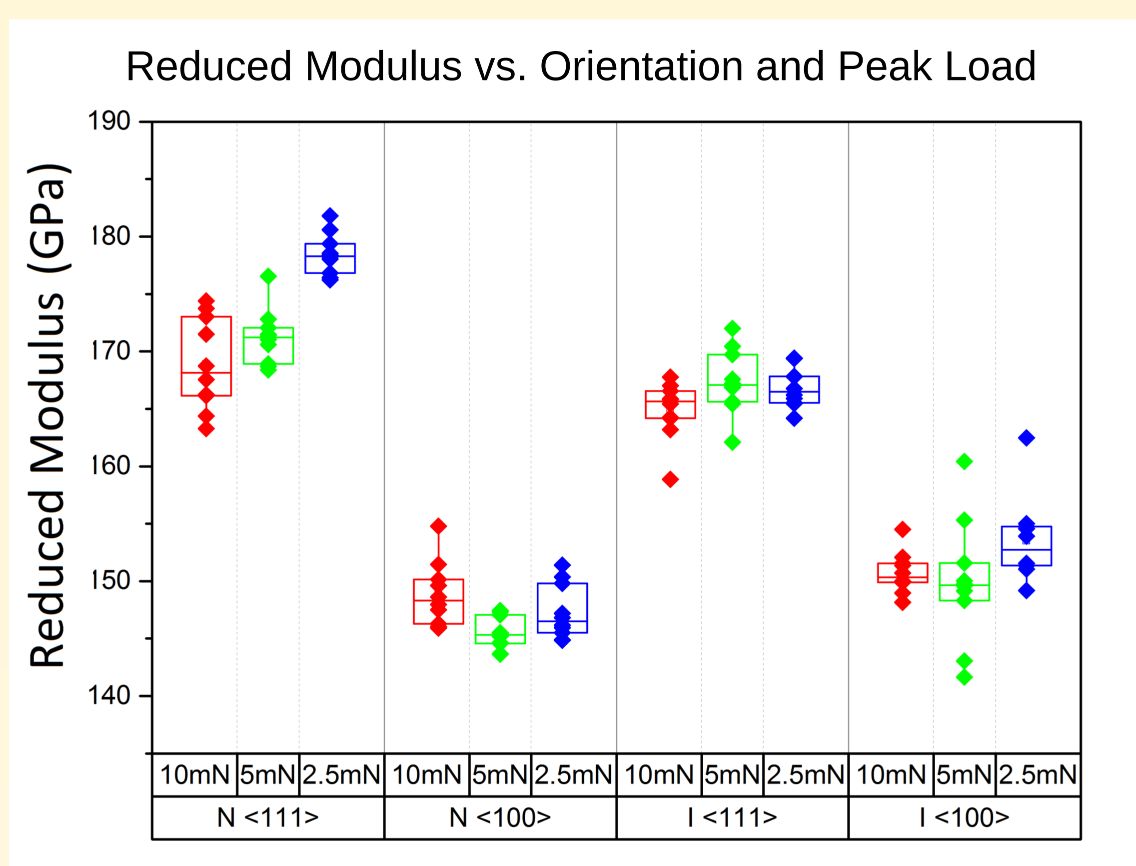
Results:

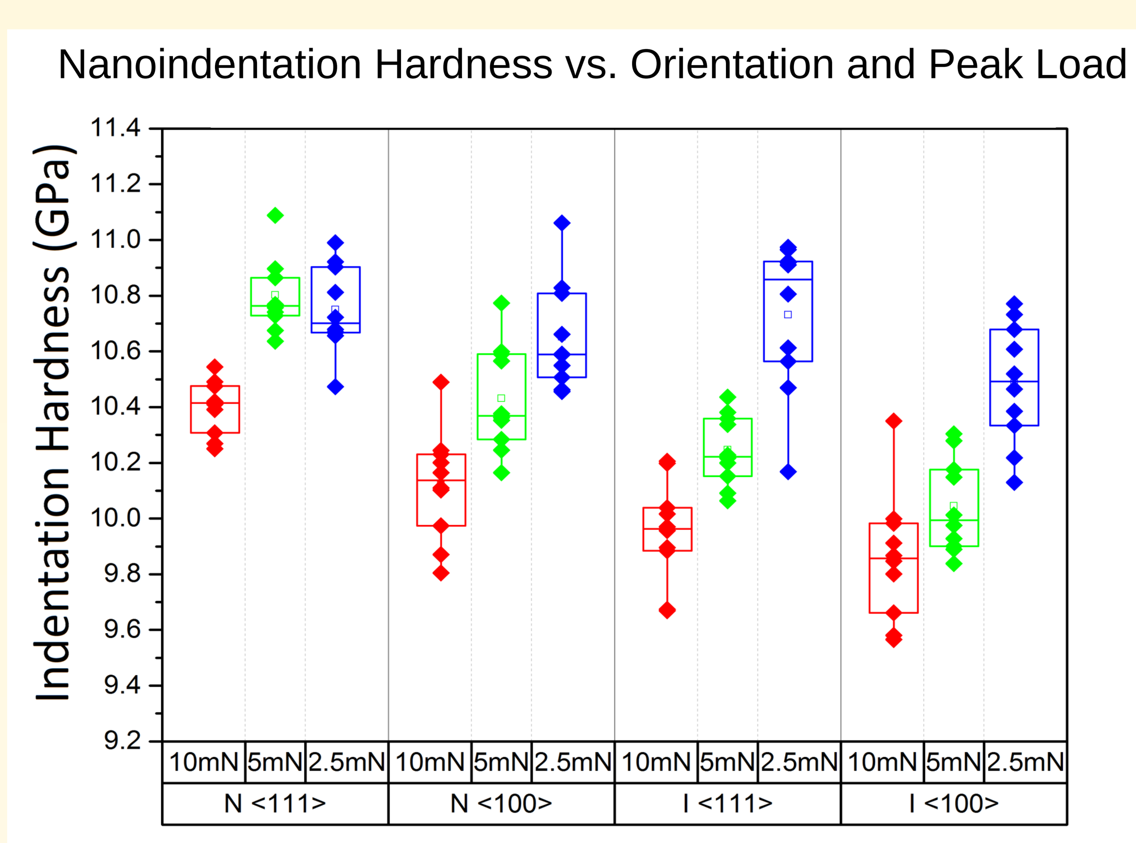
Crystal Orientation and Doping

Sample Load-Displacement Curves recorded by the Triboindenter for the for n-type silicon are shown below.



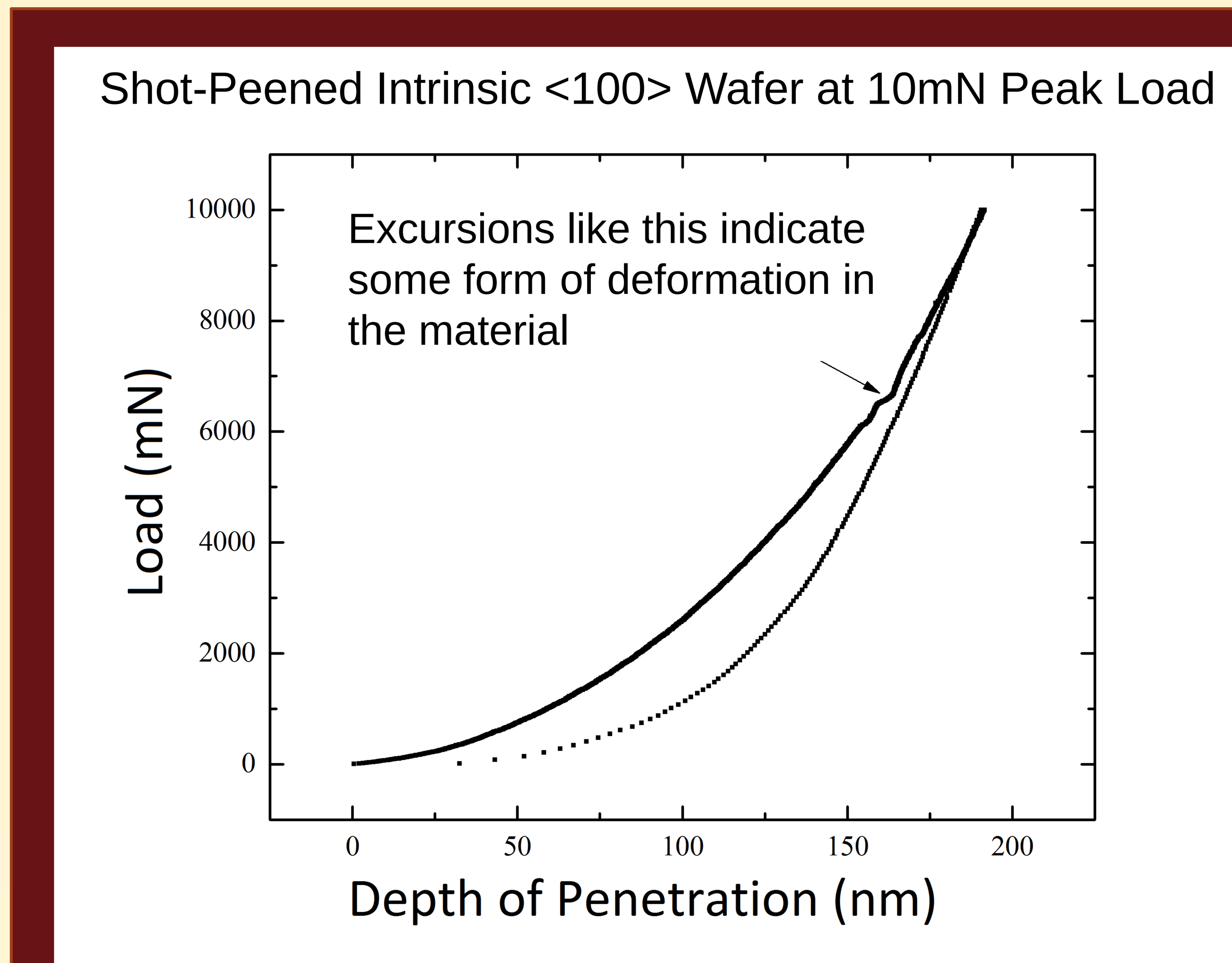
Hardness and Modulus were also recorded by the Triboindenter based on the shape of the load-displacement curve.





Shot Peening

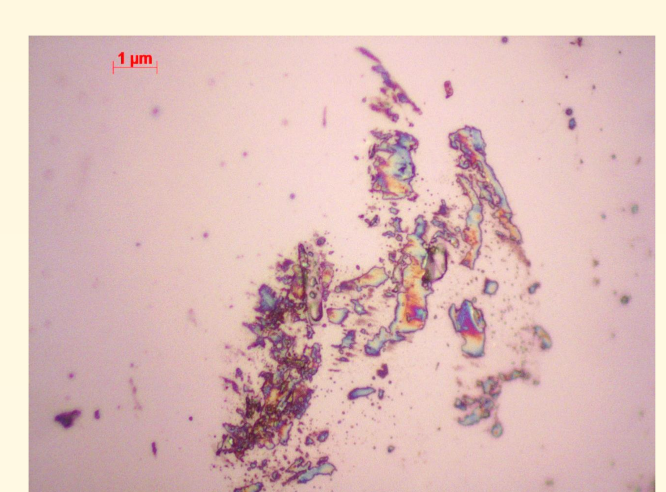
Two indents with a max load of 10mN were performed on the shot-peened sample. One indent yielded particularly interesting results



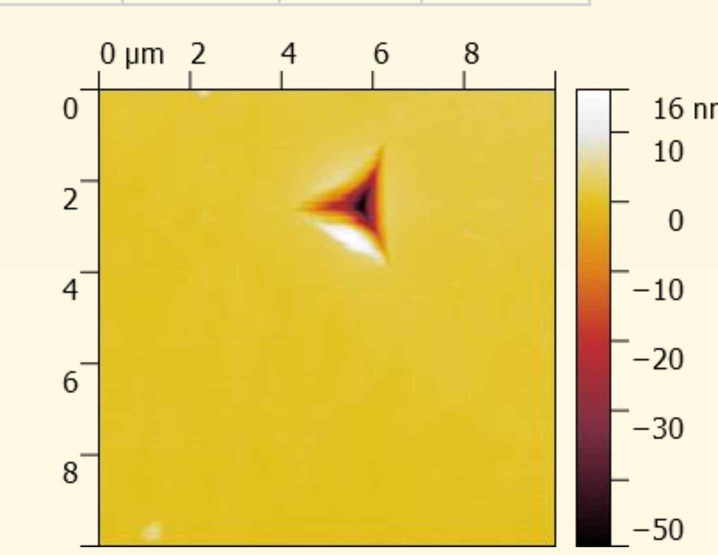
Excursions in the load-displacement curve were identified for a 10mN load in shot peened Si, but were not observed in other samples. It is believed that his excursion is due to fracture rather than ductile yielding.

Data collected from 2.5mN max load indentations near a crater on the shot-peened sample.

Distance From Crater (μm)	25	25	60	75
Hardness (GPa)	11.3	10.6	11.1	10.8
Reduced Modulus (GPa)	150.7	155.3	151.0	158.3
Distance From Crater (μm)	15	40	65	90
Hardness (GPa)	10.9	10.9	10.1	11.2
Reduced Modulus (GPa)	152.3	157.6	150.1	158.7



Above: Microscope image of shot-peened surface



Above: AFM image of the 10μN indent corresponding to the graph below

Conclusion

- The <100> orientation had a lower modulus than <111>.
- Given corrections for instrument compliance and drift, doping did not have a noticeably effect on hardness and modulus.
- The craters formed by the glass shot did not produce stress fields within a range 25μm.
- The fracture toughness of the shot peened sample was *less* than that of the pristine samples.
- Shot peening induced considerable damage to the specimens, and most likely created cracks which lowered the fracture toughness.

Future Directions

- The fact that shot peening had an effect on mechanical properties indicates that there is still interest in investigating surface deformation in bulk Si
- More precise measurements of fracture toughness can also be completed through SEM and indentation at higher loads.
- Shot-peening in the experiment was volatile and uncontrollable. Devices such as pressure gages could be used to control the deformation of shot, and reduce it to beneficial levels.
- Heating the Silicon to high temperatures may lesson the amount of damage and create more dislocation activity.

References

1. Callister and Rethwish, "Materials Science and Engineering, 9ed," Wiley and Sons, 2014.
2. Fischer-Cripps, A. "Nanoindentation," Springer, 2011

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